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NPS CENTER FOR AUTONOMOUS UNDERWATER VEHICLE (AUV) RESEARCH

2003 ANNUAL REPORT

by

Sean Kragelund, editor

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13. ABSTRACT

This report presents a summary of the work completed in 2003 at the NPS Center for Autonomous Underwater Vehicle (AUV) Research and provides a preview of future work planned for 2004.

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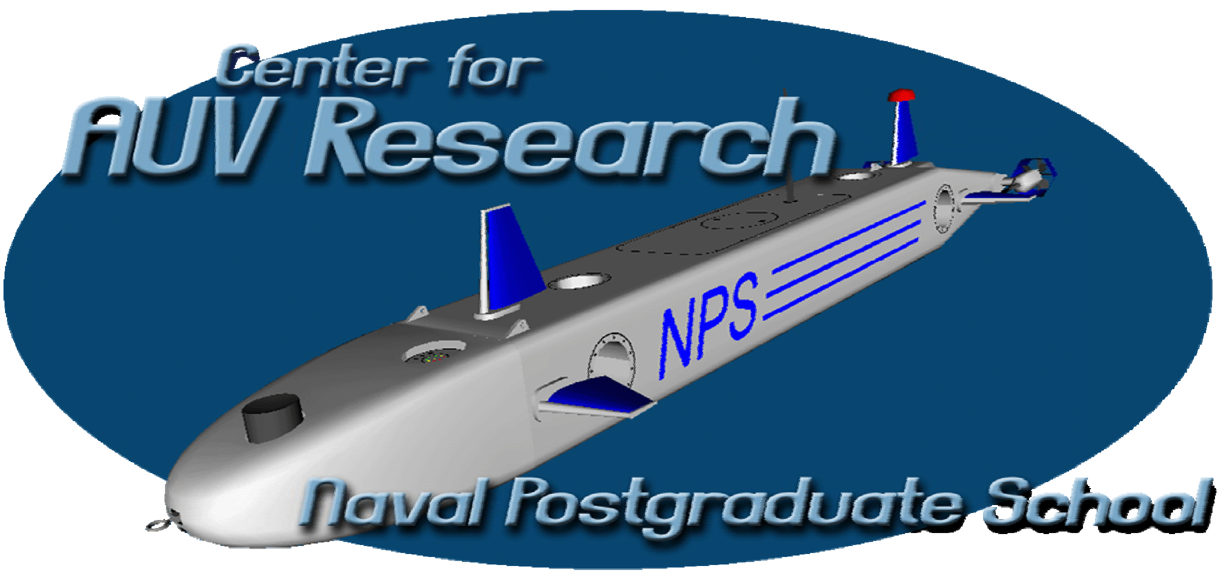

http://www.cs.nps.navy.mil/research/auv/

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Figure 1: NPS Center for AUV Research faculty and staff. First row (L to R): Anthony Healey, Don Brutzman, Doug Horner. Second Row: Dale Danko, Keith Jones, Jack Nicholson. Third Row: Matt Phaneuf, Kwang Song, Jeff Weekley.

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Overview

The Center for Autonomous Underwater Vehicle (AUV) Research is located at the Naval Postgraduate School (NPS) in Monterey, CA. The Center began in 1987 when interested faculty from the Departments of Mechanical Engineering, Computer Science, and Electrical and Computer Engineering teamed up to support the Navy's plans to use robotic vehicles for clandestine mine countermeasures (MCM). As research in this area continued, interest in autonomous underwater vehicles for commercial and scientific applications grew. As a result, AUV technology matured considerably. Although operational systems have become more common, they still face difficult challenges. The Center conducts research that develops and applies technology to overcome these challenges.

The primary goal at the Center for AUV Research is to educate the Navy's future leaders in the development and use of AUV technology by providing advanced coursework, thesis, and dissertation research. Since its inception, the Center has received funding for several projects from sponsors such as the Office of Naval Research (ONR), Naval Undersea Warfare Center (NUWC), Naval Explosive Ordnance Disposal Technology Division (NAVEOD-TECHDIV), and the National Science Foundation (NSF). This research has supported over 120 theses and dissertations since 1987.

Another major goal of the Center is to advance naval unmanned underwater vehicle (UUV) operations. To achieve this goal the Center provides:

- independent verification and validation of AUV technologies;
- innovative concept development, modeling and simulation;
- support to the fleet, navy labs, and program offices through participation in technology demonstrations and fleet battle experiments (FBE); and
- research supporting two Future Naval Capabilities (FNCs) proposed by ONR, *Autonomous Operations (AO)* and *Very Shallow Water Mine Countermeasures (VSWMCM)*.

The Center has designed and built three underwater vehicles, beginning with the NPS AUV I. This small remote-controlled submersible gave way to the *Phoenix*, a completely autonomous, highly maneuverable vehicle built for student research into shallow-water MCM. The *Phoenix* could swim using two stern propellers and four paired control surfaces (bow and stern dive planes and top and bottom rudders) or hover using four cross-body thrusters. Its rectangular cross section could accommodate diverse payloads, allowing students to experiment with several different sensors and control system architectures.

The *Phoenix* played a valuable experimental role, but retired from service when the Center began designing its next-generation vehicle, the ARIES. While most *Phoenix* operations occurred in test tanks at the NPS campus, the ARIES is a fully operational multi-vehicle network server performing regular runs in Monterey Bay. The Center has recently acquired a second operational AUV, the commercially available REMUS, to conduct research into collaborative multi-vehicle operations using acoustic communication.

To support low-risk, high-value AUV development and testing, the Center for AUV Research has developed a physics-based virtual world that incorporates vehicle-specific hydrodynamics and high-speed 3D graphics. This tool allows researchers to test and evaluate new vehicle control code from the safety of a workbench before deploying expensive hardware at sea.

While past AUV research largely focused on MCM applications and the development of advanced control methodologies to enable operations in shallow water, current research interests include:

- navigation, control, and undersea communications;
- collaborative multi-vehicle operations;
- obstacle detection, mapping, and avoidance using forward-look sonar (FLS);
- tactical decision aids (TDAs) for mission planning, rehearsal, experimentation, and visualization;
- development of a common AUV mission command language to allow interoperability among rapidly proliferating proprietary vehicle systems.

The Center for AUV research enjoyed a busy and exciting year in 2003. Its ARIES and REMUS vehicles participated in a large multi-institutional oceanographic field experiment over three weeks in August. In addition, the Center deployed these vehicles regularly to support research in vehicle control, acoustic communications, and sonar imaging. Further advances in tactical decision aids continued to produce new and improved tools for AUV development. Research at the Center for AUV Research accounted for five graduate degrees (four MS and one PhD) conferred by NPS in 2003. This report presents a summary of the work completed over the last year and provides a glimpse at some of the work planned for 2004.

AUV Research and Development

Vehicles

The Center for AUV Research has been designing, building, and operating AUVs since 1987. At present, the Center regularly deploys two different vehicles to support AUV research: the ARIES and the REMUS.

ARIES

The Acoustic Radio Interactive Exploratory Server (ARIES) became fully operational in 2000. Slightly larger than the *Phoenix*, ARIES is about 3 m long and weighs about 225 kg. Its aluminum pressure hull has a rectangular cross-section about 0.4 m wide x 0.25 m high. The flooded fiberglass nose houses the vehicle's external sensors, including an RD Instruments Navigator Doppler velocity log (DVL) and Benthos acoustic modem. Depending on the mission, the nose can also accommodate additional sonar or video sensors. ARIES navigates using its RDI DVL, Honeywell HMR 3000 electronic compass, Kearfott KG-2001 gyro, and Systron Donner Motion Pak inertial measurement unit (IMU). While surfaced, ARIES uses the differential global positioning system (D-GPS) to correct any accumulated navigational errors.

Figure 2: ARIES being lowered into Monterey Harbor.

Powered by six 12 volt lead-acid batteries, ARIES can achieve speeds of 3.5 knots on missions up to four hours in duration. Like its predecessor, the ARIES has bow and stern planes for normal flight and vertical and lateral cross-body thrusters for slow-speed maneuvers. Unlike the *Phoenix*, however, ARIES was designed without bottom rudders and could—in the future—perform bottoming maneuvers. External stern-mounted electric thrusters provide simpler, more reliable propulsion than the *Phoenix*'s stern propellers.

The ARIES was conceived as a network server vehicle to enable cooperative operations by multiple AUVs. It provides a communications link between a command post and underwater network nodes such as bottom-mounted sensors or other AUVs. Submerged, ARIES uses acoustic communications and can serve as a data relay to increase the communication range of networked underwater assets. On the surface, ARIES uses high-bandwidth radio communications with a command ship to transmit data or receive new orders. The ARIES demonstrated this capability during the Monterey Bay Field Experiment by downloading data from an underwater sensor and relaying it to a support vessel (see AUV Operations, below).

Future improvements planned for early next year will extend ARIES vehicle communications even further. These upgrades will include a new antenna and wireless networking hardware to enable 802.11b radio ethernet communications between ARIES and its support ship via an aircraft relay. The Center will perform operational testing of the new hardware during the fifth Surveillance and Target Acquisition Network (STAN 5) experiment at Camp Roberts, CA prior to demonstrating this new capability with ARIES at the Combined Joint Task Force Exercise (CJTFEX) 04-2 in June 2004.

The Center continues to deploy ARIES regularly as a developmental platform. Its rectangular cross-section makes it easy to install and evaluate various payloads, while its communications systems provide operational flexibility. Using its radio link, engineers can not only download mission data, but also upload, compile, and execute new mission scripts or control code—even while at sea. These unique capabilities make ARIES an invaluable AUV research tool.

REMUS

Remote Environmental Monitoring UnitS (REMUS) are commercial AUVs designed by the Woods Hole Oceanographic Institution (WHOI). The US Navy has been using variants of these AUVs to assist mine clearing operations in Iraq. Last year, under a grant from the Office of Naval Research (ONR), the Center purchased its own REMUS system to conduct research in collaborative multi-vehicle operations. The REMUS is small (1.6 m), lightweight (37 kg), and easy to transport. Its user-friendly mission planning and data analysis software enable quick turnarounds, making this vehicle convenient for frequent operations in Monterey Bay.

REMUS navigates using long-baseline sonar relative to a pair of transponders suspended in the water column. It can also home in on one transponder using ultra-short baseline sonar or, absent an acoustic fix, navigate via dead-reckoning using its RDI DVL. The vehicle is equipped with side-scan sonar for bottom imaging as well as standard oceanographic sensors for measuring conductivity, temperature, depth (CTD), current, and optical backscatter (OBS). Although REMUS has a top speed of 5 knots, it can perform 20+ hour missions at its optimum speed of 3 knots.

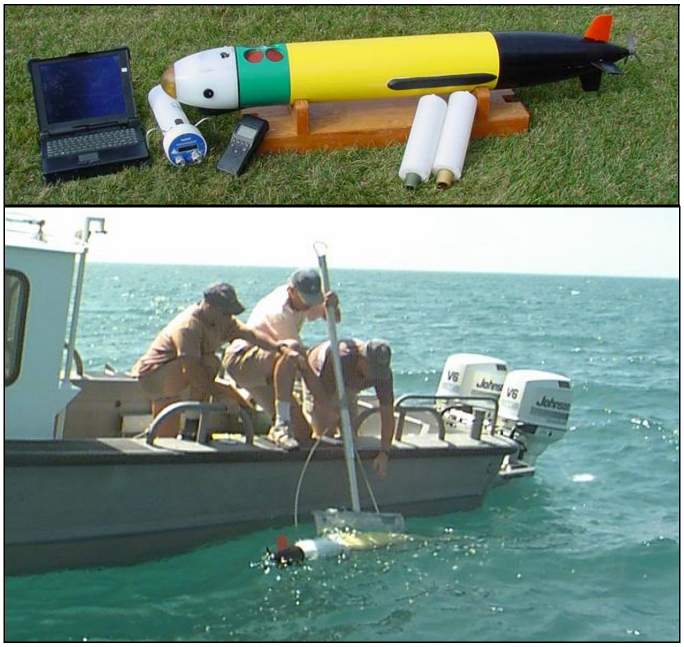

Figure 3: REMUS system on display (above) and during deployment in Monterey Bay (below).

With the addition of the REMUS system, the Center for AUV Research has gained new operational capabilities such as side-scan sonar mapping of the ocean bottom. REMUS, together with the ARIES, will also enable the Center to conduct multi-vehicle experiments in acoustic communications and cooperative behavior.

Research

Navigation, Control, and Undersea Communications

Much of the Center's 2003 thesis research was conducted in these three subject areas, which are often mutually supportive. Tactical control of AUVs depends upon reliable undersea communication. For a doctoral dissertation on shallow water acoustic control of underwater vehicles, CDR William J. Marr spent considerable effort characterizing the performance of two commercial acoustic modems installed on the ARIES AUV. This work helped quantify the limits of relatively high-speed acoustic data transfer (1200 bps) for this vehicle. Experiments demonstrated successful acoustic control of the ARIES for low data rates (55-220 bps), but indicated that high-speed data transfer was extremely range-limited. This research suggested that control strategies for achieving and maintaining reduced vehicle separation might maximize data transfer rates, leading to related research in multi-vehicle operations.

Additional control system research involved designing and testing an autopilot to steer the ARIES vehicle when surfaced. Due to its lack of bottom rudders, differential thrust is required for the ARIES to maintain course while subjected to wind and wave disturbances on the surface. This type of steering control can enable ARIES to communicate over radio links that use geosynchronous satellites, which are located at fixed positions in the sky. After several experiments, LT Christopher J. Sarton concluded that wave-induced motions limit the effectiveness of differential-thrust autopilots on ARIES. Further work in this area is needed to achieve robust surface steering with the ARIES vehicle.

Collaborative Multi-Vehicle Operations

High-bandwidth underwater communications are critical for enhanced operations with multiple AUVs. Expanding on the acoustic control and communications work described above, research was conducted to determine methods for achieving optimal AUV rendezvous. In such scenarios, a server vehicle intercepts a target vehicle and remains in close proximity to conduct high-bandwidth data transfer (Figure 4). For cooperative operations, the server vehicle may have prior knowledge of all future target maneuvers. This knowledge makes optimal rendezvous possible, although solutions may be either time optimal or energy optimal depending on mission objectives. Future work in this area will include modification of the ARIES software to enable dynamic, autonomous mission creation for AUV rendezvous.

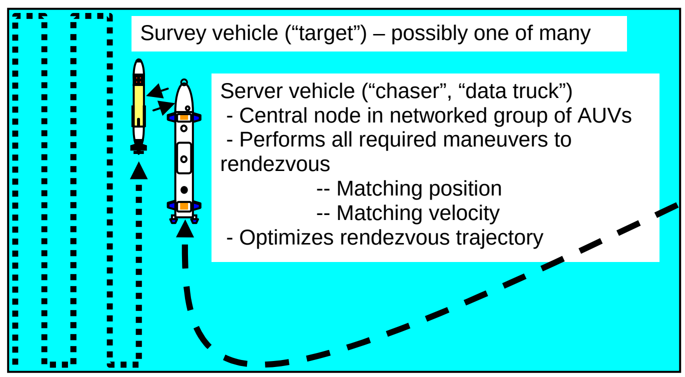

Figure 4: Typical scenario depicting a server vehicle rendezvous with a survey vehicle for in-stride data transfer.

Other research in multi-vehicle operations resulted in algorithms and rules designed to enable "follow the leader" behaviors during AUV rendezvous. These behaviors, based on ranging and intention information shared between vehicles via acoustic communications, support better high-speed data transfer between a leading and a following vehicle. These behaviors are designed to support future multi-vehicle operations including cooperative search or cooperative navigation, whereby one "smart" AUV with high-resolution navigation sensors is able to correct the dead-reckoning errors of other "dumb" AUVs in the group.

Obstacle Detection, Mapping, and Avoidance Using Forward-Look Sonar (FLS)

Obstacle avoidance is important to safe, successful AUV navigation in crowded littoral environments. Past research at the Center has studied obstacle avoidance control for the REMUS vehicle in the horizontal plane. Since most AUVs operate by following a prescribed track, obstacle avoidance in the horizontal plane must determine how to avoid the obstacle while minimizing off-track error. Last year this research was extended to the vertical plane. In each case, the range to the detected obstacles determines whether the vehicle should invoke deliberative or reflexive avoidance behavior. Since the REMUS lacks forward-look sonar (FLS) for obstacle detection, this research used mathematical models for both the vehicle and the FLS. This year the Center for AUV Research began applying this research using actual FLS hardware mounted on the ARIES vehicle.

The Center has teamed with the Applied Physics Lab at the University of Washington (APL-UW) and the Applied Research Laboratories of The University of Texas at Austin (ARL:UT) on an ONR program to develop low power sonar systems for small to mid-size UUVs. Under this program ARL:UT is responsible for implementing an FLS system and obstacle avoidance behaviors on the Naval Special Warfare Semi-Autonomous Hydrographic Reconnaissance Vehicle (SAHRV). The NPS Center for AUV Research is leading the initial data collection effort for a blazed-array FLS system developed by APL-UW.

In 2003 the Center worked with APL-UW to integrate the sonar array, electronics, and software onto the ARIES vehicle. The ARIES performed several data collection missions alongside the Monterey Municipal Wharf and underway in Monterey Bay. The FLS imagery collected during these missions was made available to the research community via a secure data server to support development of obstacle detection and avoidance algorithms. Upcoming tasks for 2004 include construction of a next-generation blazed-array sonar at APL-UW for permanent installation on the ARIES, continued software development, and implementation of obstacle-avoidance algorithms.

Research Partnerships

The Center for AUV Research has entered into many successful research partnerships over the years, of which the FLS program is just one example. This year the Center signed a Cooperative Research and Development Agreement (CRADA) with the National University of Singapore's Temasek Defense Systems Institute (TDSI). Under this agreement NPS will provide TDSI with copies of the AUV Workbench, AUV Data Server, and geometry models of the ARIES and REMUS vehicles published in open literature. This will enable TDSI to begin developing new guidance and control algorithms for operations in the surf zone. Next year these algorithms will be implemented on the ARIES vehicle for in-water validation testing in Monterey Bay.

Tactical Decision Aids (TDAs)

Over the years, the NPS Center for AUV Research has developed numerous Tactical Decision Aids (TDAs) for AUV mission planning, rehearsal, experimentation, and visualization. These tools have been continually expanded through the combined efforts of past and present NPS students and faculty.

AUV Data Server (ADS)

One of the first TDAs developed at the Center was the AUV Data Server (ADS). The ADS was originally designed to convert data gathered from various unclassified AUV systems into a format usable by the fleet's Mine warfare Environmental Decision Aids Library (MEDAL). MEDAL is a classified mine countermeasures software package used by operational personnel to evaluate asset positions, bathymetry maps, mine-like contacts, and sonar images of contacts and identified mines.

The ADS was first demonstrated during Fleet Battle Experiment (FBE)-Hotel in 2000. It soon evolved from a manual system requiring user interaction to an automatic system capable of running on the ARIES server vehicle to perform data conversion with reduced delay, as demonstrated at FBE-India (2001) and FBE-Juliet (2002). The ADS has also been used in Kernel Blitz, a major Navy and Marine Corps exercise held biennially to evaluate systems and tactics for the littoral region. Presently, ADS software enables 3D graphical playback of actual AUV missions over the Internet by linking an AUV data repository to the AUV Workbench simulator.

Scenario Authoring and Visualization for Advanced Graphics Environments (SAVAGE)

The SAVAGE project supports web-based authoring and 3D visualization of scenarios comprised of dynamic graphical models. Scenarios ranging in complexity from a single AUV mission to a full-scale amphibious raid can be constructed from an extensive library of open-license models and authoring tools created using Extensible 3D (X3D) graphics. The SAVAGE archive contains over eight hundred high-resolution models of military ships, aircraft, land vehicles, robots, terrain, environmental effects, etc contributed by students and researchers over the years. This archive is a flexible and powerful resource for the visualization of modeling and simulation results.

AUV Workbench

The AUV Workbench was developed to provide realistic, physics-based modeling and simulation of underwater vehicles and sensors in a virtual world. This allows researchers to develop and test new control algorithms safely removed from the rigors of actual undersea operations. It is a powerful development tool that also supports distributed mission planning, simulation, and visualization. Upcoming work will enable the Center to use the AUV Workbench for mission planning and experiment validation while underway during AUV operations.

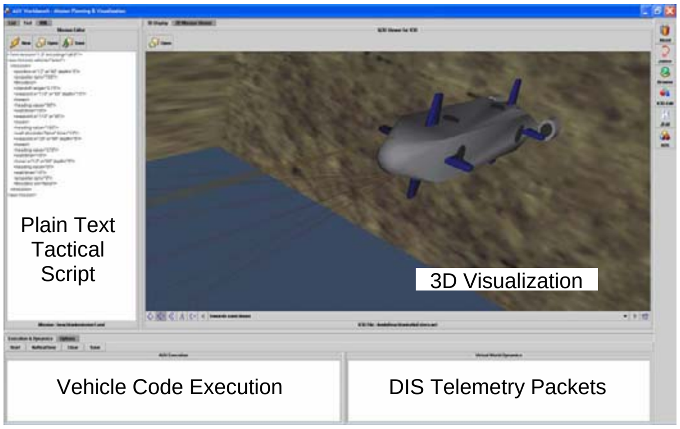

Figure 5: AUV Workbench screenshot illustrating its four main display panels.

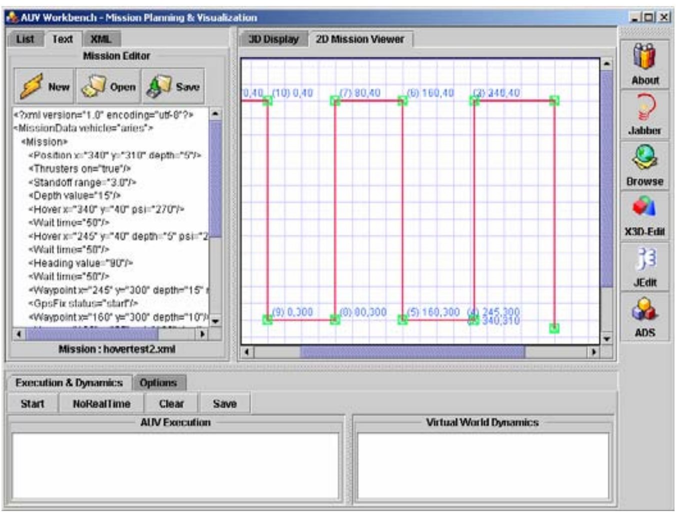

Figure 6: AUV Workbench screenshot showing its graphical mission planning and generation tool.

The AUV Workbench consists of four main control threads communicating directly or over a network:

1. A mission execution thread runs the actual control software from the AUV of interest. Vehicle telemetry data is obtained from the physics-based virtual world instead of its onboard sensors.
2. A virtual world dynamics thread updates vehicle state using telemetry strings from the execution thread, vehicle-specific hydrodynamics, and physics based models of vehicle sensors.
3. A mission visualization thread uses a 3D viewer to render graphical models of the vehicle, sensors, and virtual environment.
4. A graphical user interface allows simple mission planning and generation (Figure 6).

The AUV Workbench uses the Distributed Interactive Simulation (DIS) standard developed by the Institute of Electrical and Electronics Engineers (IEEE) to broadcast vehicle state information packets over a network. DIS allows an AUV simulation in one location to be displayed in another, supporting playback of archival mission data stored on the AUV data server. DIS also allows researchers to create large joint simulations using a mixture of individual simulation entities. These capabilities make the AUV Workbench useful for collaborative vehicle development.

The mission planning capabilities of the AUV Workbench were recently improved by the incorporation of Extensible Markup Language (XML). XML provides formatted, self-describing data which can be validated and easily translated into other formats. Using open-source tools, users can design interfaces to convert the XML-based mission scripts generated by the AUV Workbench into mission scripts for use on their particular vehicle system. In this way, the AUV Workbench can serve as a common mission planning and analysis tool for different vehicle systems. In the future, XML-based tools will facilitate interoperability between disparate proprietary vehicle systems.

Common AUV Mission Command Language

To accomplish this goal the Center for AUV Research is conducting research into a common, XML-based AUV mission command language. Such a language facilitates interoperability without modification to existing vehicle systems so that each might enjoy other advantages inherent to XML. XML is both human and machine readable, and XML documents can be accessed via a hypertext transfer protocol (HTTP) server. Their validity can be guaranteed by writing and applying a schema, i.e. a set of rules that the document must follow. Furthermore, the repetitive tags used to compose verbose XML documents can be replaced by “tokens” to enable efficient binary compression and serialization. This approach permits efficient data transfer, data checking, and forward error correction (FEC) in the transferred files. Binary compression of XML mission scripts has already been integrated directly into the AUV Workbench. Further work will add Hamming codes for FEC to improve messaging reliability without retransmission.

Two other TDAs under development at NPS are expected to provide new and improved capabilities to warfighters at sea: Sonar Visualization and XML Tactical Chat.

Sonar Visualization and Tactical Web Services for Undersea Warfare

The sonar visualization project uses 3D graphical tools and XML web technologies to provide USW operators and mission planners with relevant real-time sonar analysis. This tool will develop intuitive, interactive ways of displaying 3D sonar propagation results computed from physics-based models. XML will enable the generation of consistent 3D displays from different sonar modeling systems, and web services will provide connections between high-performance computing centers on the mainland and real-time tactical applications at sea.

This work has resulted in a recent upgrade to the AUV Workbench, using Recursive Ray Acoustics (RRA) algorithms developed at NPS to incorporate 3D sonar visualization into the virtual world. This feature will be expanded to include sonar-to-object collision detection using the geometric computation capabilities of the Xj3D open-source browser. This combination will effectively provide "virtual sonar" for even greater physical realism during laboratory testing.

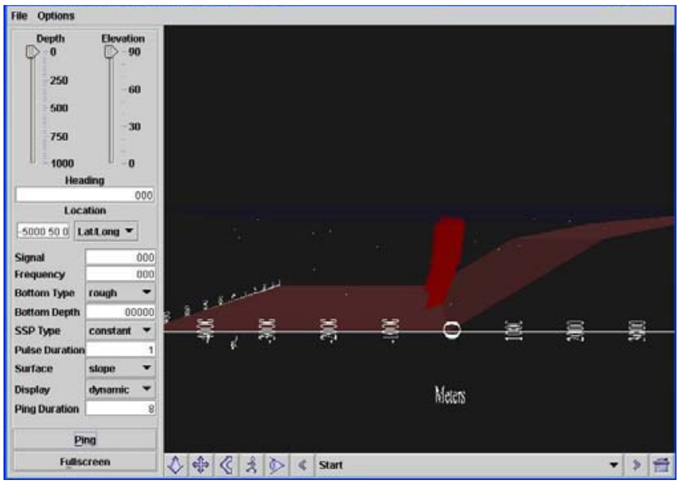

Figure 7: Screenshot of sonar visualization panel recently added to the AUV Workbench.

XML Tactical Chat (XTC)

XML Tactical Chat has enormous potential not only to overcome the limitations of current commercial chat tools, but also to revolutionize tactical military communications. Chat, text-based communications using Internet Protocol (IP), has been in use for many years. The military uses commercial chat software for some tactical communications, but the wide variety of competing proprietary tools limit joint interoperability. These tools also raise licensing and security questions, may not cross network firewalls, and often lack the ability to properly log or search prior chat sessions.

XML Tactical Chat (XTC), by comparison, uses free open-source software based on the Jabber instant messaging and presence protocols. One main advantage of Jabber is that it uses structured XML formats to bridge multiple platforms and protocols. Because XTC messages are themselves XML documents, they may contain formatted binary data as well as plain text. In this way XTC can provide fast, reliable communications for both humans and machines simultaneously.

XTC technologies can also support cooperative autonomous operations by providing asynchronous data transfer among arbitrary numbers of dissimilar vehicles, intelligent agents, or human operators. Furthermore, XTC sessions can be logged and stored automatically to facilitate data retrieval and mission reconstruction. This promising technology is currently being incorporated into the AUV Workbench. With this addition, future collaborative experiments are expected to reap significant new benefits in distributed development, testing, and mission evaluation.

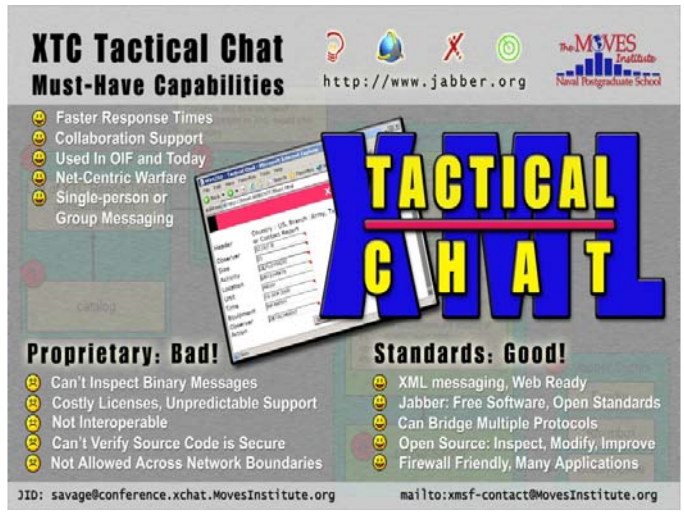

Figure 8: Poster summarizing the advantages of XML Tactical Chat (XTC) over proprietary chat programs.

Extensible Modeling and Simulation Framework (XMSF)

In cooperation with government, academic, and industry experts, NPS is defining an Extensible Modeling and Simulation Framework (XMSF) for exploiting web-based technologies on a global scale. Such a framework has great promise to transform current modeling and simulation (M&S) systems to meet the broad training, analysis, acquisition, and warfighting needs of tomorrow, while leveraging mainstream best practices for enterprise-wide software development and deployment.

XMSF is currently defined as a composable set of standards, profiles, and recommended practices to enable web-based M&S. Web-based technologies can support interoperability for the full spectrum of M&S applications, including constructive, virtual, and live environments. Such technologies can also integrate legacy simulation frameworks with distance-learning technologies to support operational warfighters anytime, anywhere.

XMSF provides the technical basis for transformational interoperability through the application of open standards, XML-based markup languages, internet technologies, and cross-platform Web services. To accomplish this transformation, XMSF must enable simulations to interact directly and scalably over a highly distributed network; must be equally usable by human and software agents; and must support composable, reusable model components.

The AUV Workbench and Sonar Visualization TDAs represent two XMSF-enabled projects that support M&S over the Web. They exemplify one of the main precepts of XMSF: that web-based technologies applied within an extensible framework will enable a new generation of M&S applications to emerge, develop, and interoperate.

AUV Operations

AOSN-II Monterey Bay Field Experiment

The Center for AUV Research participated in a large field experiment in Monterey Bay last August. NPS deployed its ARIES and REMUS vehicles as autonomous nodes in a diverse oceanographic sensing network. Both vehicles logged long hours on near-daily missions to collect and relay measurement data for use by oceanographers. The ARIES missions allowed the Center to apply its research in acoustic control and communications to demonstrate AUV rendezvous and high-speed data transfer with an underwater sensor. The REMUS missions provided an opportunity to collect meaningful oceanographic data while evaluating the vehicle's sensor performance. The following section provides background information on the significance of this field experiment and describes the Center's AUV missions in more detail.

Background

Conventional oceanographic measurement systems offer only a limited ability to observe the ocean in real-time. Oceanographic surveys performed by manned research vessels are slow, costly, and usually confined to a relatively small geographic area over periods of days or weeks. Instruments on remote moorings can collect data as long as battery power permits, but cannot reposition themselves to respond to changing local conditions. Such methods typically produce only a meager dataset, making it difficult for oceanographers to observe, model, or predict the complex physical and biological processes in our world's oceans. Future improvements in oceanography depend on new systems to sample the ocean on a greater temporal and spatial scale than is currently possible.

For several years ONR has funded a multi-institutional effort to develop an Autonomous Oceanographic Sampling Network (AOSN) that might finally achieve economical large-scale ocean sampling. The AOSN vision comprises multiple low-cost AUVs working within a network of distributed sensors and moorings to perform continuous long-term environmental monitoring. In its first five years the AOSN project focused on developing necessary vehicle and network technologies such as acoustic communications, docking stations, and data recovery/broadcast techniques. Scientific field experiments conducted in 1998, 1999, and 2000 successfully demonstrated many of these new capabilities.

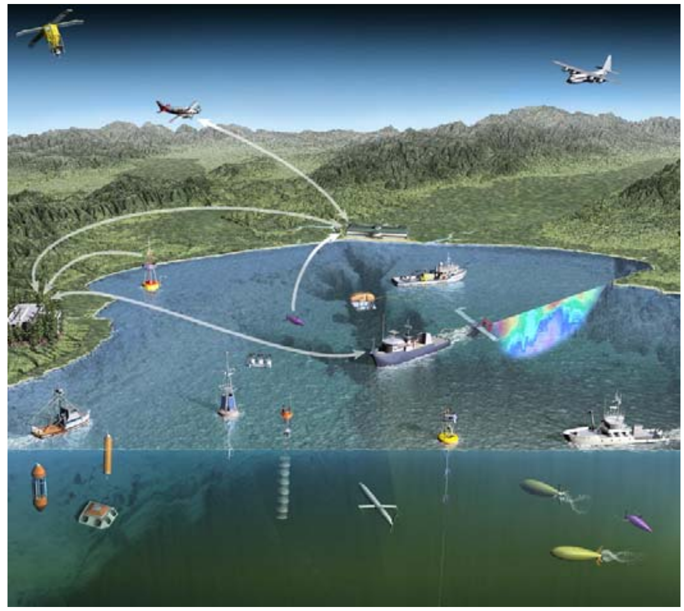

Figure 9: Autonomous Oceanographic Sampling Network (AOSN) conceptual drawing from the Monterey Bay Aquarium Research Institute (MBARI) website (http://www.mbari.org/muse).

The next challenge for AOSN is to combine autonomous sensing platforms with adaptive sampling strategies and established modeling and data assimilation packages. These "adaptive coupled observation/modeling systems" have great potential to improve oceanographic forecast accuracy by 1) assimilating sensor data into numerical forecast models, 2) generating new sampling plans in response to changes in the environment, and 3) commanding mobile assets to new locations which optimize sensor effectiveness—all with near-real-time response. ONR has chartered the AOSN-II program to quantify the improvements in predictive skill achievable by coupling these technologies. The Monterey Bay Aquarium Research Institute (MBARI) hosted the first AOSN-II experiment over a three-week period last summer. The Monterey Bay 2003 Field Experiment welcomed researchers from over a dozen institutions and deployed a record number of AUVs, including the NPS ARIES and REMUS vehicles.

ARIES Missions

The ARIES AUV performed several missions in an AOSN-II experiment to demonstrate underwater data communications between a fixed underwater sensor and a mobile vehicle. For these missions, the ARIES acted as a "data bus" between a bottom-mounted sensor and a mobile command ship. The bottom sensor, an upward-looking acoustic Doppler current profiler (ADCP) connected to an acoustic modem, was mounted in a trawl-resistant bottom mount (TRBM) and placed on the sea floor in 70 meters of water (Figure 10). The ADCP recorded one-minute current averages and logged this data into the acoustic modem buffer every four minutes.

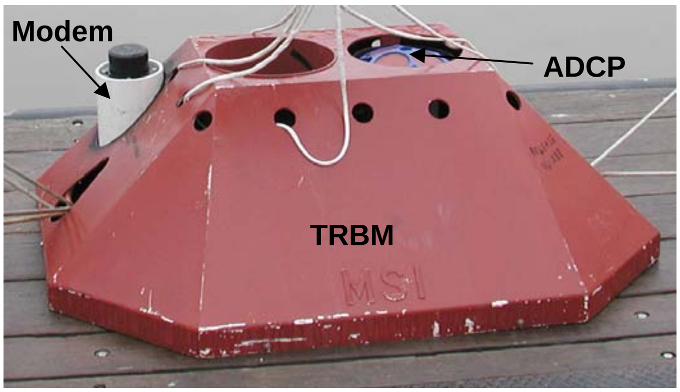

Figure 10: An acoustic modem and acoustic Doppler current profiler (ADCP) were housed in a trawl-resistant bottom mount (TRBM) during AOSN-II.

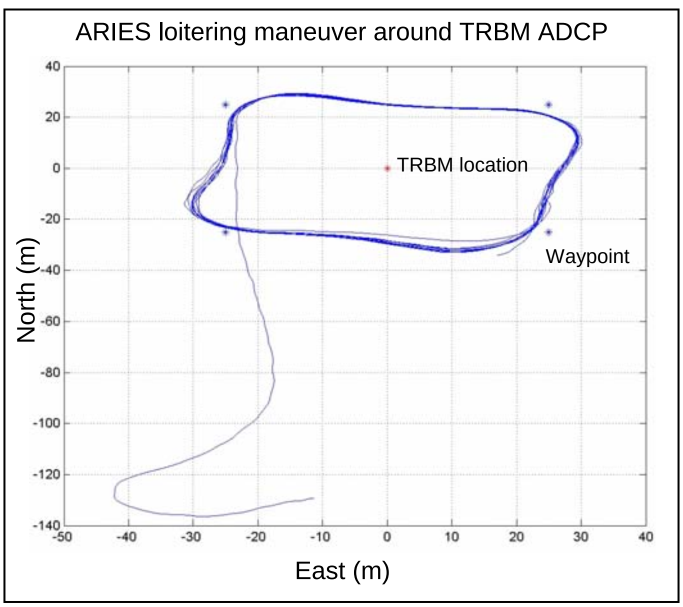

Figure 11: ARIES mission plot showing the loitering manuever commanded during data relay.

Each day, ARIES navigated to the TRBM location using its acoustic modem to verify range to the ADCP. After arriving on station, the ARIES AUV began circling the TRBM to establish modem communications with the ADCP (Figure 11). The ARIES then queried the ADCP modem for the amount of accumulated data, requested a file transfer, and continued circling the TRBM until download completion. After retrieving the ADCP data, the ARIES surfaced and relayed the data to the command post over a radio communication link for display on the NPS Department of Oceanography website (Figure 12):

http://www.oc.nps.navy.mil/~icon/moorings/aosn_adcp.html.

The experiment was a success, achieving autonomous acoustic transmission of large (up to 400 KB) data files at 1200 bps data rates on a daily basis. Over 500 MB of sensor data were transferred through the water by ARIES during AOSN-II.

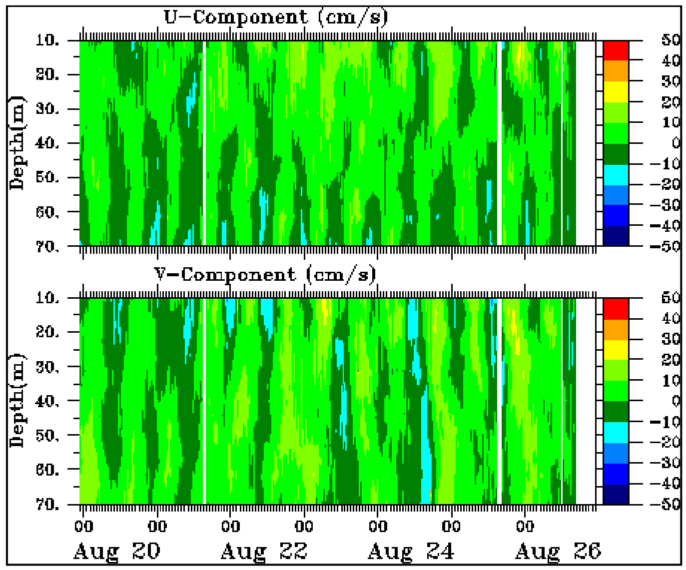

Figure 12: Contour plots of ocean current generated using acoustic Doppler current profiler (ADCP) data retrieved by ARIES.

The ARIES also supported two other experiments during AOSN-II. One utilized ARIES as an underwater node on an acoustic modem network comprised of the bottom-mounted ADCP, the ARIES vehicle, and a manned surface vessel. This enabled real-time observation and data collection from the command post. The other used the ARIES onboard ADCP to collect shallow water current data for comparison against data from a shore-based Coastal Ocean Dynamics Applications Radar (CODAR) system.

REMUS Missions

The REMUS AUV performed several long transect runs across the southern half of Monterey Bay. REMUS traveled over 20 nautical miles (18 km) round-trip from the shallow waters off the coast of Fort Ord to MBARI's M1 instrument buoy and back (Figure 13). On each four-hour mission the AUV followed a saw tooth trajectory, oscillating between 3 and 50 meters depth to collect vertical profile data along its track. The REMUS used conductivity, temperature, depth, and optical backscatter sensors to measure the properties of the water column. Finally, this measurement data was delivered to the NPS Department of Oceanography for post-processing and display on the web (Figure 14):

http://www.oc.nps.navy.mil/~icon/moorings/remus_ctd.html.

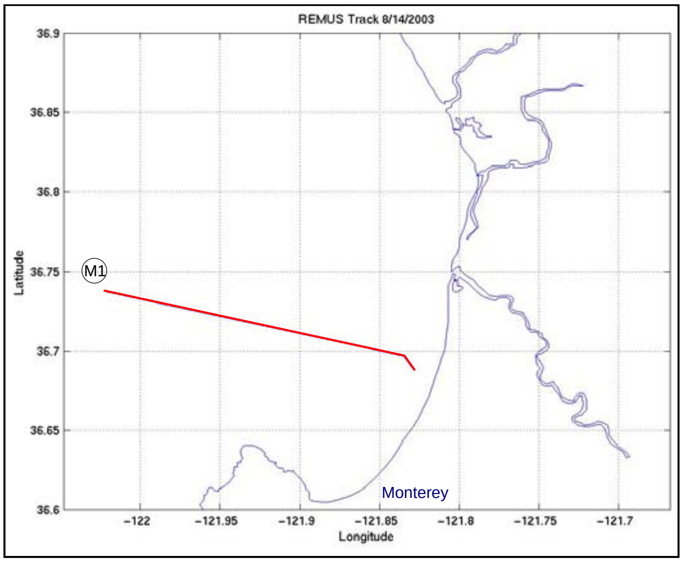

Figure 13: Plot of REMUS track data from a long transect mission across Monterey Bay to M1 buoy.

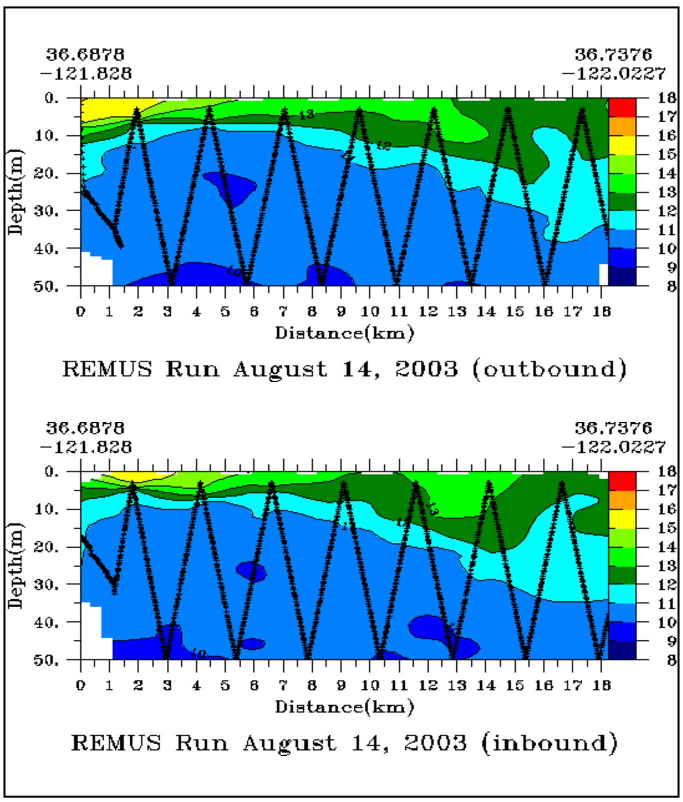

Figure 14: Contour plots of ocean temperature generated from REMUS sensor data.

The REMUS missions performed for the AOSN-II experiment not only collected useful oceanographic data about Monterey Bay, but also provided NPS researchers with an opportunity to evaluate the vehicle's navigational accuracy and sensor performance.

Research Support Operations

Although missions supporting the Monterey Bay Field Experiment accounted for most of the Center's vehicle deployments last year, several other missions were performed in support of student research. The diverse capabilities of the ARIES vehicle make it a valuable experimental platform. Its ability to carry a variety of payloads enables a degree of hardware integration testing not found on most operational AUVs. The ARIES software architecture and radio communications link make software developmental testing easy, even while underway. Researchers used the ARIES extensively to characterize acoustic modem performance for tactical control and high-speed data transfer, laying the groundwork for the capabilities demonstrated during AOSN-II. Researchers also conducted missions to test various surface steering autopilots and verify initial hardware/software integration of a blazed-array forward-look sonar (FLS).

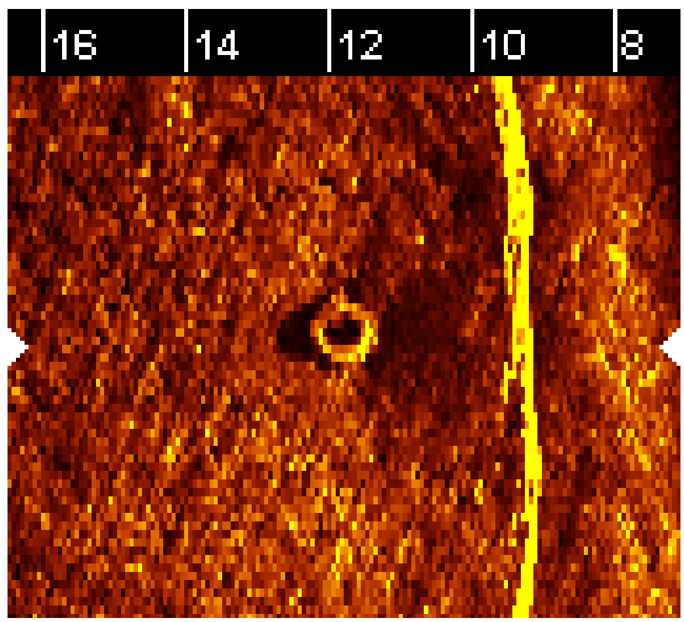

Figure 15: REMUS side-scan sonar image of a mine-like object on the ocean floor.

The Center also conducted several missions using the REMUS system. These missions gave students experience with REMUS mission planning and data analysis software, and also allowed them to evaluate the vehicle's sensor performance. Initial deployments involved near-shore hydrographic mapping to aid FLS obstacle avoidance research, as well as bottom object detection and localization. The latter deployments entailed locating an object on the ocean floor with side-scan sonar and using imaging software to pinpoint its location (Figure 15). Researchers then programmed the REMUS to circle the object's location and collect enough data to evaluate the statistical accuracy of side-scan localization. These experiments were performed using mine-like objects supplied by MObile Mine Assembly Unit 1 (MOMAU1, Seal Beach, CA) as well as the NPS Department of Oceanography's Monterey Inner Shelf Observatory (MISO).

Summary

The Center for AUV research enjoyed a busy and exciting year in 2003. The Center conducted several AUV operations in support of cutting-edge vehicle research, and participated in a multi-institutional oceanographic field experiment. Other research produced new and improved tools for AUV development, modeling, and simulation. In the coming year, continued research will enhance the Center's capabilities even more. Planned vehicle upgrades include 802.11b radio ethernet, new blazed-array forward-look sonar, and obstacle-avoidance software for the ARIES, as well as GPS-positioning capability for the REMUS. The resulting vehicle integration testing, along with scheduled Center participation at numerous technology demonstrations and Fleet exercises in 2004, should make for another exciting and challenging year. As always, the NPS Center for AUV research will welcome each challenge while performing its unique educational and technological mission.

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Massachusetts Institute of Technology (MIT) Sea Grant AUV Lab websites: http://auvlab.mit.edu/research/mvo.html and http://auvlab.mit.edu/MURI